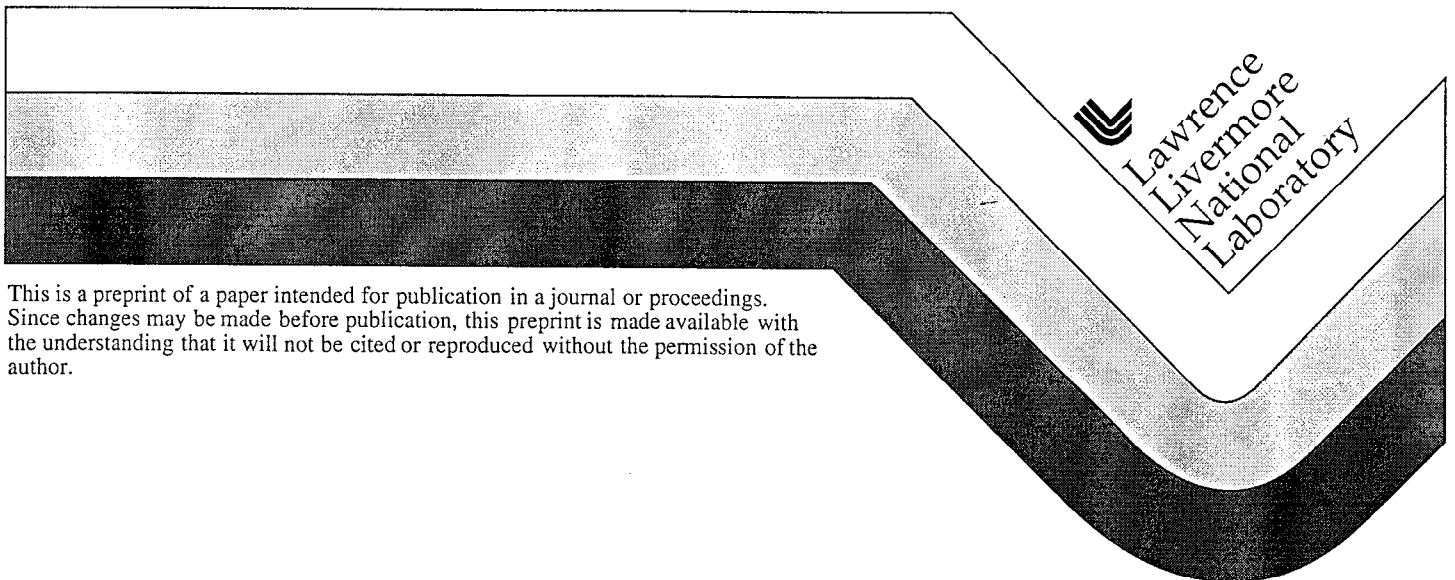


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This paper was prepared for submittal to the  
11th APS Topical Conference on Shock Compression  
of Condensed Matter  
Snowbird, UT  
June 27-July 2, 1999

June 1999



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# SHOCK SENSITIVITY OF LX-04 AT 150C

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Hazard scenarios can involve multiple stimuli, such as heating followed by fragment impact (shock). The shock response of LX-04 (85 weight % HMX and 15 weight % Viton binder) preheated to temperatures near 150C is studied in a 10.2 cm bore diameter gas gun using embedded manganin pressure gauges. The pressure histories at various depths in the LX-04 targets and the run distances to detonation at several input shock pressures are measured and compared to those previously obtained in ambient temperature and 170C LX-04. Since the beta to delta phase transition in HMX occurs at 165C, these experiments are designed to determine whether the observed increase in shock sensitivity is due in part to the 6% volume expansion caused by this phase transition. The experimental shows that LX-04 exhibits the same sensitivity at 150C and 170C. The Ignition and Growth reactive flow model developed for 170C LX-04 works equally well for LX-04 at 150C.

## INTRODUCTION

The relative safety of high energy materials based on octahydro-1,3,5,7-tetranitro-1,3,5,7-tetrazocine (HMX) is very important. LX-04, which contains 85 weight % HMX and 15 weight % Viton binder, is a widely used HMX-based plastic bonded explosive. The sensitivity of LX-04 to a single stimulus such as heat, impact, and shock has been studied. Hazard scenarios can involve multiple stimuli, such as heating to temperatures close to thermal explosion conditions followed by fragment impact, producing a shock in the hot explosive. This scenario has previously been studied for triaminotrinitrobenzene (TATB)-based insensitive solid explosives under various thermal and confinement conditions (1-3). The shock sensitivity of unconfined and confined LX-04 heated to 170C has been compared to that of ambient temperature LX-04 using embedded manganin pressure gauges (4) and reactive flow calculations (5) in previous papers (6,7). The sensitivity of HMX at elevated temperatures is complicated by the beta to delta solid state phase transition, which occurs at approximately 165C. This paper presents the results of a series of shock initiation experiments conducted with LX-04 preheated to 150C. At this temperature, the phase transition and its 6% volume expansion does not

occur. Thus it can be determined whether the observed increase in shock sensitivity at 170C is totally due to the increased growth of reaction at these elevated temperatures or is partially due to the transition to a more sensitive solid phase.

## EXPERIMENTAL

The experimental geometry for the heated LX-04 embedded gauge experiments is shown in Fig. 1. A

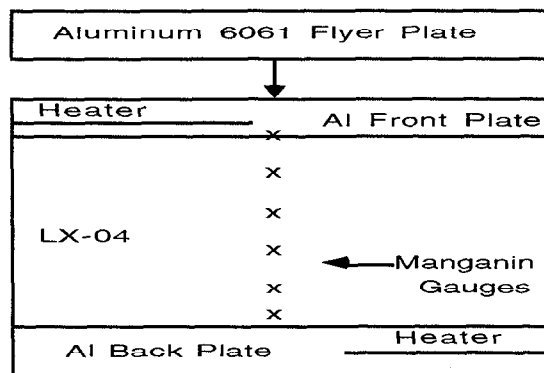


FIGURE 1. Geometry of the heated LX-04 embedded manganin pressure gauge experiments

12.7 mm thick, 90 mm diameter aluminum flyer plate impacted a target consisting of a 6 mm thick, 90 mm diameter aluminum buffer plate, a 20 mm thick, 90 mm diameter LX-04 charge and a 6 mm thick, 90 mm diameter aluminum back plate. Heaters were placed within the aluminum plates, and the LX-04 was heated to approximately 150C at a rate of 10C/minute. When the nine thermocouples in the aluminum and LX-04 showed that the whole assembly was within a few degrees of 150C, the shot was fired. Three shots with aluminum flyer velocities of 0.594, 0.701, and 1.08 mm/ $\mu$ s produced shock pressures of 2.5, 3.4, and 5.5 GPa, respectively. Six manganin pressure gauges placed along the LX-04 charge axis measured the pressure histories at 0, 5, 10, 13, 16 and 18 mm into LX-04 in the 0.594 mm/ $\mu$ s shot, at 0, 5, 8, 10, 12, and 15 mm in the 0.701 mm/ $\mu$ s shot, and at 0, 3, 5, 7, 10, and 15 mm into LX-04 in the 1.08 mm/ $\mu$ s shot.

### REACTIVE FLOW MODELING

The Ignition and Growth reactive flow model uses two Jones-Wilkins-Lee (JWL) equations of state, one for the unreacted explosive and another one for the reaction products, in the temperature dependent form:

$$p = A e^{-R_1 V} + B e^{-R_2 V} + \omega C_V T/V \quad (1)$$

where  $p$  is pressure in Megabars,  $V$  is relative volume,  $T$  is temperature,  $\omega$  is the Gruneisen coefficient,  $C_V$  is the average heat capacity, and  $A$ ,  $B$ ,  $R_1$  and  $R_2$  are constants. The equations of state are fitted to the available shock Hugoniot data. The reaction rate law is:

$$\begin{aligned} dF/dt = & I(1-F)^b(\rho/\rho_0-1-a)^x + G_1(1-F)^c F^d p^y \\ & 0 < F < F_{igmax} \quad 0 < F < F_{G1max} \\ & + G_2(1-F)^e F^g p^z \\ & F_{G2min} < F < 1 \end{aligned} \quad (2)$$

where  $F$  is the fraction reacted,  $t$  is time in  $\mu$ s,  $\rho$  is the current density in  $g/cm^3$ ,  $\rho_0$  is the initial density,  $p$  is pressure in Mbars, and  $I$ ,  $G_1$ ,  $G_2$ ,  $a$ ,  $b$ ,  $c$ ,  $d$ ,  $e$ ,  $g$ ,  $x$ ,  $y$ , and  $z$  are constants. This three term reaction rate law models the three stages of reaction generally observed during shock initiation of pressed solid explosives (5). The equation of state parameters for 150C LX-04, aluminum, and Teflon, and the Ignition and Growth rate law parameters are listed in Table 1. Roth (8) found that the density of PBX

9404 at 150C decreased from 1.84 to 1.77  $g/cm^3$ . Craig (9) reported a density of 1.79  $g/cm^3$  for PBX 9501 at 150C. The density of LX-04 is assumed to be 1.79  $g/cm^3$  at 150C (423K). Thus the only changes in the 150C LX-04 parameters from the 170C LX-04 parameters are a slightly higher initial density (1.79  $g/cm^3$ ), the initial temperature 150C (423K), and a lower  $B$  value in the unreacted JWL equation of state so that  $p=0$  at  $V=1$  and  $T_0 = 423K$ .

### COMPARISON OF RESULTS

Table 2 contains the experimental flyer velocities, impact pressures, and run distances to detonation for three 150C LX-04 shots. Figure 2 shows the measured and calculated pressure histories at the six gauge locations in 150C LX-04 impacted by an aluminum flyer plate at 0.594 mm/ $\mu$ s. The gauge records and calculations show that this input shock pressure of 2.5 GPa causes detonation to occur between the 10 mm and 13 mm gauge depths.

Two other comparisons for 150C LX-04 are shown in Figs. 3 and 4. Figure 3 contains the records for the 0.701 mm/ $\mu$ s aluminum flyer impact velocity experiment. The gauge records and calculations show that the transition occurs at the 8 mm gauge position for a shock pressure of 3.4 GPa. Figure 4 shows the results for the 1.08 mm/ $\mu$ s flyer velocity shot, which

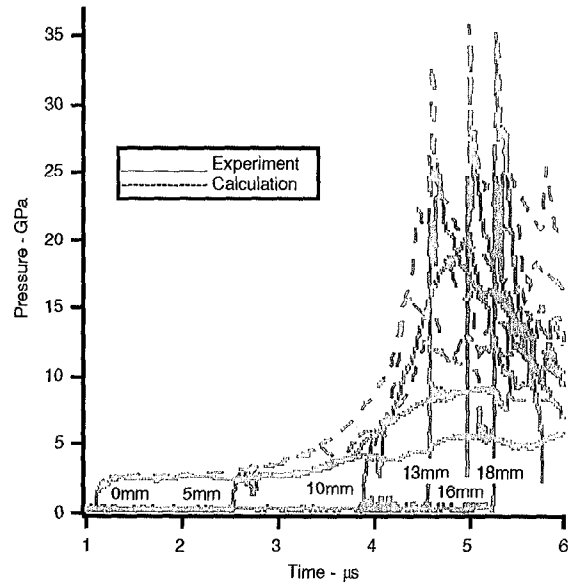


FIGURE 2. Pressure histories for ambient temperature LX-04 shock initiated by an aluminum flyer plate at 0.594 mm/ $\mu$ s

**TABLE 1.** Equation of State and Reaction Rate Parameters

## 1. Ignition and Growth Model Parameters for 150C LX-04

$T_0=423\text{K}$ ;  $\rho_0=1.79\text{ g/cm}^3$ ; Shear Modulus=0.0474 Mbar; Yield Strength=0.002 Mbar

Unreacted JW	Product JW	Reaction Rate Parameters	
A=9522 Mbar	A=8.364 Mbar	I=7.43e+11	G <sub>2</sub> =400
B=-0.0720636 Mbar	B=0.1298 Mbar	a=0.0	e=0.333
R <sub>1</sub> =14.1	R <sub>1</sub> =4.62	b=0.667	g=1.0
R <sub>2</sub> =1.41	R <sub>2</sub> =1.25	x=20.0	z=2.0
$\omega=0.8867$	$\omega=0.42$	G <sub>1</sub> =210	F <sub>igmax</sub> = 0.3
C <sub>V</sub> =2.7806e-5 Mbar/K	C <sub>V</sub> =1.0e-5 Mbar/K	y=2.0	F <sub>G1max</sub> =0.5
	E <sub>0</sub> =0.095 Mbar	c=0.667, d=0.333	F <sub>G2min</sub> =0.5

## 2. Gruneisen Parameters for Inert Materials

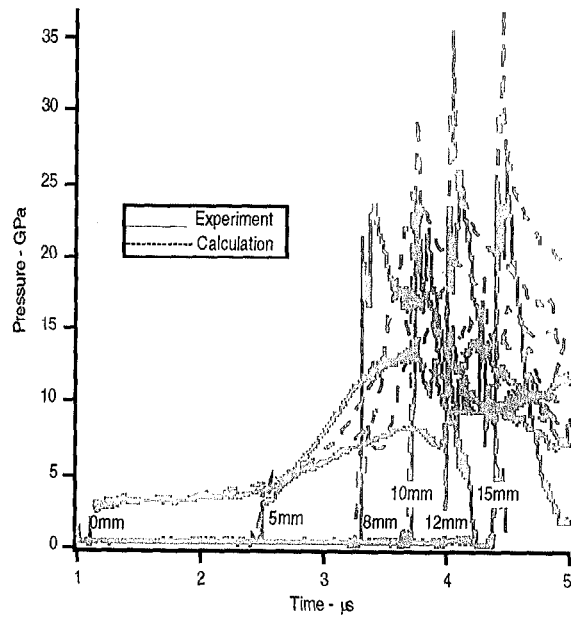
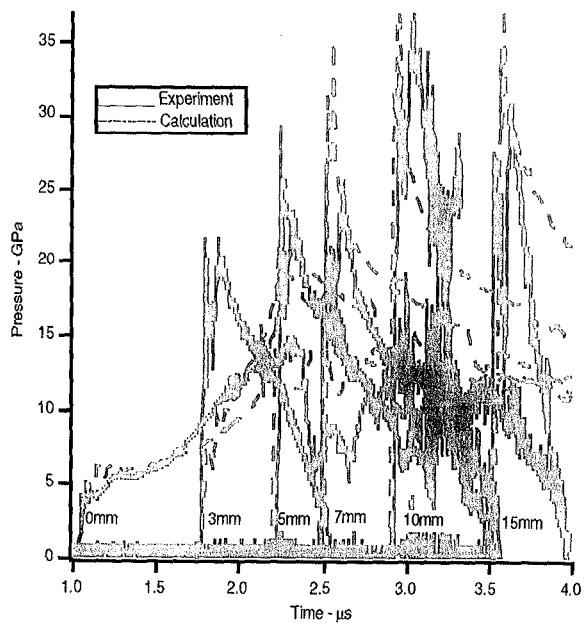
$$p = \rho_0 c^2 \mu [1 + (1 - \gamma_0/2)\mu - a/2\mu^2] / [1 - (S_1 - 1)\mu - S_2\mu^2/(\mu + 1) - S_3\mu^3/(\mu + 1)^2 + (\gamma_0 + a\mu)E]$$

where  $\mu = (\rho/\rho_0) - 1$  and E is thermal energy

Inert	$\rho_0(\text{g/cm}^3)$	c(mm/ $\mu\text{s}$ )	S <sub>1</sub>	S <sub>2</sub>	S <sub>3</sub>	$\gamma_0$	a
6061-T6 Al	2.703	5.24	1.4	0.0	0.0	1.97	0.48
Teflon	2.15	1.68	1.123	3.98	-5.8	0.59	0.0

**TABLE 2.** Experimental flyer velocities, impact pressures, and run distances to detonation

Flyer Velocity (mm/ $\mu\text{s}$ )	Impact Pressure (GPa)	LX-04 Temperature (C)	Experimental Run to Detonation Results	
			Distance(mm)	Time( $\mu\text{s}$ )
0.594 (Al)	2.5	147-151	13	4.6
0.701 (Al)	3.4	146-150	8	2.6
1.080 (Al)	5.5	146-150	3	0.9

**FIGURE 3.** Pressure histories for 150C LX-04 shock initiated by an aluminum flyer at 0.701 mm/ $\mu\text{s}$ **FIGURE 4.** Pressure histories for 150C LX-04 shock initiated by an aluminum flyer at 1.080 mm/ $\mu\text{s}$

imparts 5.5 GPa into the LX-04 and causes detonation in approximately 3 mm. The agreement of the calculations based on 170C LX-04 data with the three sets of gauge records in Figs. 2, 3 and 4 clearly demonstrates that 150C LX-04 exhibits essentially the same sensitivity as it does at 170C.

The shock sensitivity of LX-04 at 150C is shown in terms of run distance to detonation versus input shock pressure in Fig. 5. Also shown in Fig. 5 are the "Pop Plots" for ambient temperature LX-04 and PBX 9404 (10) and the data for confined and unconfined LX-04 at 170C. The run distances to detonation for 150C LX-04 fall very close to those for 170C LX-04. Roth (9) and Craig (10) measured similar trends for PBX 9404 and PBX 9501, respectively, at 150C. In fact, Craig's five run distances to detonation at different shock pressures for 150C PBX 9501 are very close to the LX-04 run distances measured at 150C and 170C.

## SUMMARY

The shock sensitivity of LX-04 heated to 150C has been quantitatively demonstrated to be very similar to that of 170C LX-04. This implies that the increased sensitivity of LX-04 at temperatures approaching the critical temperature for thermal decomposition is mainly due to the faster growth of hot spot reactions following ignition and not to increased shock sensitivity of the delta phase of HMX. However, the previous experiments with LX-04 heated to 170C were fired approximately one hour after the explosive reached 170C. Since solid – solid phase transitions are sometimes quite slow, HMX at 170C for one hour may not have had sufficient time to fully or even partially convert from the beta to delta phase. The chemical kinetic model of Tarver et al. (11) for LX-04 predicts that 90 mm cylindrical charges can be held at 170C for over 24 hours without undergoing thermal explosion. Thus, to allow the HMX more time to phase convert, gas gun shots are planned with LX-04 targets held at 170C for 24 hours before initiation.

## ACKNOWLEDGMENTS

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory (contract no. W-7405-ENG-48).

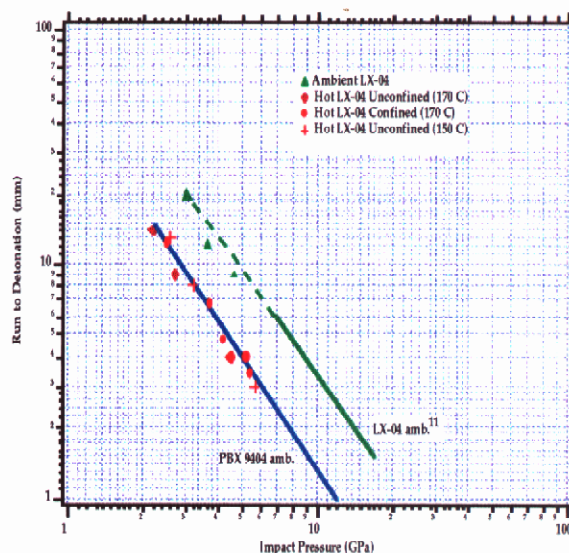


FIGURE 5. Run distance to detonation versus input shock pressure for ambient and heated LX-04 and PBX 9404

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